Report to health facilities Scotland: Queen Elizabeth University Hospital and Royal Hospital for Children Glasgow risk of fire spread on external envelope of building

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Publication date:
2018

Report to Health Facilities Scotland

Queen Elizabeth University Hospital and Royal Hospital for Children Glasgow
Risk of Fire Spread on External Envelope of Building

School of Engineering and Built Environment

Report Date: March 2018

Report to Health Facilities Scotland

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Executive Summary

The Grenfell Tower fire (London, 2017) raised concerns about the potential for combustible external cladding panels, sandwich or rainscreen, to contribute to the rapid spread of fire on the outside of a building leading to rapid fire spread internally on multiple levels. Following a review of cladding systems on NHS Scotland (NHSS) buildings, The School of Engineering and Built Environment of Glasgow Caledonian University was commissioned by NHSS Health Facilities Scotland to undertake a series of fire modelling analyses and to provide a qualitative review with regard to external cladding systems on three hospitals within the NHSS Estate.

The purpose of this study was to evaluate the extent to which the combustible rainscreen cladding systems would contribute to rapid external fire spread, and potential re-entry, at Queen Elizabeth University Hospital (QEUH) and the Royal Hospital for Children (RHC) in order to inform NHS Greater Glasgow & Clyde (GG&C) decision making regarding actions/protection measures that might be necessary to ensure the safety of all patients, staff and public in the event of a fire.

A qualitative examination of the materials making up the outer envelope of the Queen Elizabeth University Hospital was carried out. The construction of all of the external envelope elements under consideration, are deemed under the Building (Scotland) Regulations to be at least 'Low Risk'; however not all are deemed to be 'Non-combustible'. Aluminium Composite Materials (ACM) panels form part of the external element of the Queen Elizabeth University Hospital (QEUH) but these are only accessible from the podium roof at fourth floor level. It is therefore considered highly improbable that malicious or accidental ignition of the ACM panels will occur.

Part of the external cladding of the Royal Hospital for Children (RHC) was identified as not having the correct cladding system installed, as specified, and this is scheduled to be replaced with cladding to meet the original specification.

Both QEUH and RHC have a high standard of passive and active fire protection together with highly trained staff to ensure that all patients, staff and public can evacuate safely in the event of fire.

Computer modelling was carried out using the software Fire Dynamics Simulator (FDS). Fire scenarios that involved the ignition of the ACM cladding from a room fire at QEUH were modelled. These indicated that the cladding was ignited by a fire plume that was external to the building. However, conditions in the rooms above the fire plume had become untenable prior to ignition of the cladding. There was no significant lateral spread of fire along the façade, therefore adjacent rooms are unlikely to be affected by the scenarios that have been considered.

It is noted that for the fire modelling to generate conditions for external spread of the fire, and ignition of the cladding, it was necessary to assume that:

i) the automatic sprinkler system failed to operate,

ii) the furnishings in the room did not comply with the requirements of SHTM 87 and that the fire load was significantly greater than is realistic in normal operational conditions,
iii) there was no active intervention/action to prevent/mitigate fire growth.

It is the conclusion of this report, based on the outputs of the fire modelling scenarios undertaken, that in the event of an internal fire the fire spread associated with the ignition of the cladding will not contribute adversely to the risk to occupants first affected in rooms close[1] to the fire or to their safe evacuation.

On the basis of the findings of this report, and advice from other sources, NHS GG&C made the decision to:
i) replace areas of combustible rainscreen cladding at the Queen Elizabeth University Hospital,
ii) replace areas of installed combustible thermal insulation with non-combustible insulation at the Royal Hospital for Children.

The decisions were made in the context of providing additional precautionary measures, and ensuring the highest level of protection, for key regional and national assets.

[1] rooms in horizontal proximity to the fire or the fire plume

Contents

1 Qualitative Review of Building Envelope Combustibility

- **Overview**

There was significant concern, following the fire and loss of life at Grenfell Tower (London, 2017) about the potential for external cladding panels, sandwich or rainscreen, to contribute to the rapid spread of fire on the outside of a building leading to rapid fire spread internally, through re-entry, on multiple levels of a building. The detailed analysis of the sequence of events, the dynamics of fire spread and the contributory factors at Grenfell Tower are under investigation. In the interim it is noted that, whilst ACM cladding panels are evidently, from the evidence currently available, a contributory factor to the Grenfell Tower tragedy, there are a number of other factors that, to different degrees, could have contributed to the fire spread, and rate of fire and smoke spread, through the building.

The other factors include, but are not limited to, the effectiveness of cavity barriers, fire stopping, fire doors, detection and alarm systems and fire load within the building: both contents and forming part of the structure.

The materials used for insulation, or to maintain the rigidity, of ACM panels will, if they are cellulosic/polymeric, burn[2]. The chemical composition of these materials, which can be modified, will determine ease of ignition and/or ability to sustain combustion in a 'real world' situation. However, these attributes are classified in fire engineering codes and the Building Regulations as the outcomes of standard test(s) and not 'real world' performance of elements of construction[3].

Health Facilities Scotland (HFS) commissioned the University to review the design and construction of the external envelope of the Queen Elizabeth University Hospital and the Royal Hospital for Children and to evaluate the implications for fire spread of the use of Aluminium Composite Material (ACM) panels as the external cladding. This qualitative section provides a report to inform the quantitative scenario analysis and the discussions with HFS and decision making by NHS GG&C.

ACM panels form part of the external element of the Queen Elizabeth University Hospital (QEUH) However, 'combustible' materials form part of the external envelope of the building where ACM panels are not the rainscreen cladding (e.g. behind external glass panels).

The construction of all of the external envelope elements under consideration, are deemed under the Building (Scotland) Regulations to be at least 'Low Risk'; however not all are deemed to be 'Non-combustible'.

The project brief focusses on the implications, in the event of ignition and external spread of a fire involving ACM cladding, for the safety of patients, and other occupants, of the hospital. The probability of occurrence of a fire and it's spread, given mitigation provisions in hospital, is therefore not directly considered.

[2] the materials will chemically react in the presence of oxygen and heat and release energy

[3] materials and product characteristics are classified in terms of the results of standardised tests that do not directly represent performance in any 'real' fire or the standard/non-technical definition of words such as 'ignitable, flammable, combustible, fire resistant'.

- **Summary**
  - **Construction**

i. From level four to the roof, the QEUH adult hospital has ACM panels on four facades of the building with North and South faces having the same materials, CM 1[4] and the East and West having the same materials CM 9.

ii. From level four to the roof the 'angled out' legs of the adult hospital are CM 1 except for the south west leg where the corner below the helipad is CM 11.

the materials CM1 and CM11 are the only areas in the Adult Hospital where ACM panels are used

iii. On the podium, from ground to the roof over the third floor, the outer skin of the Adult Hospital is constructed of either a glass panel, natural stone or brick with combustible insulation behind (CM 2, 4, 5, 6).

iv. There is no ACM identified in the Royal Children's Hospital. However, there are areas where there is external combustible cladding with combustible insulation behind it (CM 3).

v. The Royal Children's Hospital has combustible materials for insulation behind the non-combustible external cladding/rainscreen (e.g. CM 2, 4, 6).

vi. The Adult Hospital and the Royal Children's hospital are fully sprinklered therefore there is no specified fire resistance in the Technical Handbooks.

vii. There is fire stopping at each floor level and around all window openings for all of the materials/envelope constructions of the building[4].

  - **Commentary**

i. There is fire stopping at each floor level and around all window openings for all of the materials/envelope constructions of the building[4].

   a. this will prevent/mitigate against fire spread from a fire in the room through the window surround and into the combustible insulation.

   b. In the event that fire spreads into the space between the insulation and the outer cladding, irrespective of type, horizontal spread of fire along the façade will be mitigated by the vertical (intumescent) firestops that are compression fitted with the inner insulation removed before installation[5].

(the manufacturers (Lamatherm) state that for horizontally oriented firestops it is allowable for there to be up to a 25mm gap between the leading edge of the firestop and the external screen. This would allow cold smoke to spread in the cavity but the cavity would be sealed by the expansion of the firestop before temperatures capable of igniting the materials open to the cavity ignite. The manufacturers state that the firestops (cavity barriers) have 'Fire Resistance' of up to 120mins)

ii. Glazed windows would require to be subjected to localised direct flame impingement from fire in a room before failure; the inner pane of the double glazed unit would fail first *(glass fails in fire due to stresses created in a material that is not a good conductor of heat, impurities and constraints caused by differential expansion*). There would be

[4] Construction Materials listed in Appendix A: these are referenced CM 'X

[5] as per specification, this is an assumption not verified by site inspection as this is outwith scope of the project

a further period of time to failure of the second pane. The evidence is that failure is typically partial failure of glazing.

iii. The potential for fire spread from a fire in a room to the insulation behind the screen or on the external screen is mitigated by:
   a. The inner part of the exterior envelope of the building is constructed of two layers of 12.5mm thick tapered edge plasterboard with staggered joints
   b. SHTM 85, Fire Safety – Precautions in Existing Healthcare Premises which requires: *existing hospitals should have at least 75% of Textiles and Furnishings comply with SHTM 87, Textiles and Furniture: the aim should be 100% compliance. It is reasonable to expect that internal fire spread on textiles and furnishings is mitigated and that initial ignition is difficult.*
   NHS National Services Scotland have advised that QEUH is 100% compliant
   c. QEUH has automatic smoke detection/heat as appropriate. This will alert the staff to a fire incident to intervene before the fire is of a size as to cause failure of glazing or spread from the room of origin by other means.

iv. The largest internal/ward fire, based on compartment size, has 21 beds. Assuming that all fire compartment walls are appropriately constructed and service/other penetrations are protected this is the maximum extent to which a fire would spread internally and threaten external fire spread. This would only occur should if the sprinkler system failed to contain the fire to the room of origin.

v. In the case of sprinkler failure and before an operating systems failure to contain a fire, there would be early detection and alarm. Emergency Management actions to extinguish the fire, evacuate patients and, if necessary, close the door to the room of origin would contain the fire for a considerable period of time.

vi. The potential for a wilful fire raising attack on the external cladding is mitigated on the Adult Hospital as the ACM panels rise from a restricted access area at level 4.

2 Fire Modelling

Appendix B of this Report describes the fire modelling method, assumptions and outputs for the Queen Elizabeth University Hospital (QEUH) to inform decision-making associated with alternative mitigation measures in the context of the risk associated with the contribution of combustible cladding to fire spread and potential changes in regulatory requirements in Scotland. Section 3 provides a summary of the assumptions, outputs and conclusions.

3 Summary of Fire Modelling Assumptions, Outputs and Conclusions

Key Assumptions

- integrity of specified passive fire safety provisions in situ, these are correctly maintained to prevent/limit internal fire spread
- an internal room fire develops to flashover and sustains a post-flashover fire; a 16MW fire was required to model conditions that supported external fire spread
- no active intervention/action to prevent/mitigate growth to a flashover fire (including failure of/failure to respond to detection and alarm in room of origin)
- no active intervention/action to prevent/mitigate fire and smoke entry to building

Fire Modelling Outputs

- Room Fire
    - the probability of a flashover fire sustained at 16MW, as predicted by the model to be required to ignite the cladding, is extremely low as this is significantly larger than predicted for the current/actual fire load and requires that there is no active intervention following detection/alarm. The probability of an internal fire leading to ignition of the cladding is therefore very low.
    - in conditions where the combustible cladding became involved due to an internal room fire spreading out through the windows(s) the ignition of the cladding is predicted to occur after the fire had made conditions untenable in the room of fire origin and in the room(s) above. The ignition of the cladding would not have a significant impact on conditions in the upper room or on internal fire spread.

Conclusions

- the risk to occupants first affected in rooms close[6] to the fire and their evacuation would not be adversely affected by involvement of cladding in the fire.
- on the basis of the qualitative analysis and the outputs of the fire modelling it is concluded that the external cladding does not constitute an additional life safety hazard to occupants first affected in rooms close[6] to the fire in the event of a fire.

- In the context of providing additional precautionary measures, and ensuring the highest level of protection, for key regional and national assets the following decisions are supported
    - replace areas of combustible rainscreen cladding at the Queen Elizabeth University Hospital,
    - replace areas of installed combustible thermal insulation with non-combustible insulation at the Royal Hospital for Children

Large Scale Testing of Fire Spread Involving the Cladding

- it is not considered that large scale testing would provide additional information that would materially change the evaluation of the impact of combustible cladding on the fire hazard/risk at the QEUH. For large scale testing to provide useful information a number of tests for different scenarios would be required, including internal and external fires with windows open and closed.

[6] Rooms in horizontal proximity to the fire or fire plume

Appendix A Construction Materials

1	5	6	9	10	11	12	13	14	15
Project	**Location**	**Reference**	(If col 6 completed): **External wall construction**	(If col 7 completed): **Relevant fire classifications**	(If col 6 completed): **Firestopping in Void?**	**Specialist Sub-Contractor's Description**	**Specialist Sub-Contractor's Product Reference**	**Specialist Sub-Contractor's Product Fire Certification**	**Specialist Sub-Contractor's Product Fire Certification**
The Queen Elizabeth University Hospital and Royal Hospital for Children, Glasgow	Adults, Towers	1	Unitised curtain walling system fixed at floor slab levels incorporating double glazed units with fully encapsulated insulated aluminium spandrel panels, independent shaftwall system forming internal leaf clad with two layers of plasterboard to inner face and cement particle board to outer face	Reaction to fire of external wall cladding to be low risk in accordance with non-domestic technical handbook section 2.7.1	Intumescent firestops are provided horizontally at each floor level, around all window & door openings and vertically at all compartment wall junctions	Unitised aluminium curtain walling, incorporating double glazing units, fully encapsulated single glass spandrel panels with Celotex FR5000 insulation, internal steel tray panel.	25NM-SGH	Internal surface spread of flame of curtain walling Class 0 to BS 476-7. Celotex FR5000: Fire propagation BS476 part 6- Pass; Surface spread of flame BS476 part 7- Class 1. Firestopping achieved with proprietary Siderise CW-FS tested and assessed on proven fire performance to BS 476 :Part 20, and tested to EN 1364-4.	Structal confirm the installation is compliant at the time of construction and in accordance with the relevant Building Regulations at Financial Close.

The Queen Elizabeth University Hospital and Royal Hospital for Children, Glasgow	Adults & Childrens, Podium	2	Stick curtain walling system fixed at floor slab levels incorporating double glazed units with insulated ceramic unit spandrel panels on cement particle board to outer face of independent shaftwall system forming internal leaf/structural framing system clad with two layers of plasterboard to inner face	Reaction to fire of external wall cladding to be low risk in accordance with non-domestic technical handbook section 2.7.1	Intumescent firestops are provided horizontally at each floor level, around all window & door openings and vertically at all compartment wall junctions	**Prater:** Spandrel units with 6mm clear toughend float glass unit with ceramic frit to surface 2, 80mm Kingspan K15 insulation, galvanised steel liner sheet **Others:** Y-Wall board, insulated SFS system or concrete cores.	Curtain Walling	Glass: Noncombustable (Decision 94/611/EC) Structal: Rockwool Duoslab Rated A1 when tested to EN 13501-1 classification using test data from reaction to fire test. Alucobond BS476, part 6≤12i≤6, Surface spread of flame BS476 part 7-Class 1 therefor meets class 0 national building regulations. Firestopping achieved with proprietary Siderise CW-FS tested and assessed on proven fire performance to BS 476 :Part 20, and tested to EN 1364-4. K15 Insulation: Low Risk Galvanised Liner: Noncombustable (Decision 94/611/EC)	

The Queen Elizabeth University Hospital and Royal Hospital for Children, Glasgow	Childrens	3	Trespa Meteon rainscreen cladding panels on carrier system incorporating Kingspan Kooltherm K15 thermal insulation fixed to cement particle board on outer face of structural framing system with two layers of plasterboard to inner face	Reaction to fire of external wall cladding to be low risk in accordance with non-domestic technical handbook section 2.7.1	Intumescent firestops are provided horizontally at each floor level, around all window & door openings and vertically at all compartment wall junctions	**Prater:** Trespa Meteon panels, 80mm Kingspan K15, aluminium helping hand system & intumescent fire stopping.**Others:** Y-Wall board, insulated SFS system.	Trespa Rainscreen System	Trespa Meteon: TBCKingspan K15: Low Risk	
The Queen Elizabeth University Hospital and Royal Hospital for Children, Glasgow	Adults, Podium, Main Entrance Area	4	StoneLite faced cladding panels with honeycomb backing on carrier system incorporating Kooltherm K15 thermal insulation fixed to cement particle board to outer face of structural	Reaction to fire of external wall cladding to be low risk in accordance with non-domestic technical handbook section 2.7.1	Intumescent firestops are provided horizontally at each floor level, around all window & door openings and vertically at all compartmen	**Prater:** Stonelite natural stone aluminium honeycomb backed panels, 80mm Kingspan K15, aluminium helping hand system & intumescent fire stopping. **Others:** Y-Wall board, insulated SFS system.	Natural Stone Cladding	Stonelite Panels: Low Risk Kingspan K15: Low Risk	

			framing system with two layers of plasterboard to inner face		t wall junctions				
The Queen Elizabeth University Hospital and Royal Hospital for Children, Glasgow	Adults & Childrens, Podium	5	Forticrete cavity blockwork facing masonry, Kingspan Kooltherm K15 thermal insulation fixed to cement particle board on outer face of structural framing system with two layers of plasterboard to inner face	Reaction to fire of external wall cladding to be low risk in accordance with non-domestic technical handbook section 2.7.1	Intumescent firestops are provided horizontally at each floor level, around all window & door openings and vertically at all compartment wall junctions	**Prater:** Novastone Blockwork **Others:** Y-Wall board, insulated SFS system.	Brickwork	Novaston Blockwork: Noncombustable	

The Queen Elizabeth University Hospital and Royal Hospital for Children, Glasgow	Adults & Childrens, Podium	6	Sto cement-free render on EPS insulation board incorporating fire retardant additive fixed back to cement particle board on outer face of structural framing system with two layers of plasterboard to inner face	Reaction to fire of external wall cladding to be low risk in accordance with non-domestic technical handbook section 2.7.1	Intumescent firestops are provided horizontally at each floor level, around all window & door openings and vertically at all compartment wall junctions	**Prater:** Stotherm Vario render system inc EPS insulation & Lamella fire breaks. **Others:** Y-Wall board, insulated SFS system or concrete cores.	Render	Sto Vario Insulated Render System: BR 135 Test Report demonstrating suitability for use,	
The Queen Elizabeth University Hospital and Royal Hospital for Children, Glasgow	Adults & Childrens, Plantrooms	7	Kingspan KS 1000MR EcoSafe micro-rib insulated wall panels on structural framing to primary structural frame	Reaction to fire of external wall cladding to be low risk in accordance with non-domestic technical handbook section 2.7.1	Intumescent firestops are provided horizontally at each floor level, around all window & door openings and vertically at all compartment wall junctions	**Prater:** RUUKKI SP2D PIR Composite Panel**Others:** Y-Wall board, insulated SFS system.	RUUKKI Composite Cladding	RUUKKI SP2D: Low Risk	

The Queen Elizabeth University Hospital and Royal Hospital for Children, Glasgow	Childrens, Main Entrance Area	8	Rheinzinc seamed cladding system on 25mm WBP plywood on carrier system incorporating Kooltherm K15 thermal insulation fixed to cement particle board on outer face of structural framing system with two layers of plasterboard to inner face	Reaction to fire of external wall cladding to be low risk in accordance with non-domestic technical handbook section 2.7.1	Intumescent firestops are provided horizontally at each floor level, around all window & door openings and vertically at all compartment wall junctions	**Prater:** 0.8mm Rheinzink blue grey standing seam, tyvek breather membrane, 25mm FR Class 0 plywood board, 80mm Kingspan K15, aluminium helping hand system & intumescent fire stopping. **Others:** Y-Wall board, insulated SFS system.	Zinc Cladding Rainscreen System	Rheinzink: Non-combustable Plywood: Low Risk Kingspan K15: Low Risk	

The Queen Elizabeth University Hospital and Royal Hospital for Children, Glasgow	Adult, Towers	9	Unitised curtain walling system incorporating double glazed units with fully encapsulated spandrel panels formed of Reynobond aluminium panels incorporating Kingspan Kooltherm K12 thermal insulation, independent shaftwall system forming internal leaf clad with two layers of plasterboard to inner face and cement particle board to outer face	Reaction to fire of external wall cladding to be low risk in accordance with non-domestic technical handbook section 2.7.1	Intumescent firestops are provided horizontally at each floor level, around all window & door openings and vertically at all compartment wall junctions	Unitised aluminium curtain walling, incorporating double glazing units, fully encapsulated composite aluminium spandrel panels - Alucobond PE, with Celotex FR5000 insulation, internal steel tray panel.	25NM-SGH	Internal surface spread of flame of curtain walling Class 0 to BS 476-7.Celotex FR5000: Fire propagation BS476 part 6- Pass; Surface spread of flame BS476 part 7-Class 1. Alucabond BS476, part 6≤12i≤6, Surface spread of flame BS476 part 7-Class 1 therefor meets class 0 national building regulations. Firestopping achieved with proprietary Siderise CW-FS tested and assessed on proven fire performance to BS 476 :Part 20, and tested to EN 1364-4.	Structal confirm the installation is compliant at the time of construction and in accordance with the relevant Building Regulations at Financial Close.

The Queen Elizabeth University Hospital and Royal Hospital for Children, Glasgow	Helipad Area and Core Towers	11	Alucobond aluminium cladding panels on carrier system incorporating Kooltherm K15 thermal insulation fixed to cement particle board on outer face of independent shaftwall system forming internal leaf clad with two layers of plasterboard to inner face	Reaction to fire of external wall cladding to be low risk in accordance with non-domestic technical handbook section 2.7.1	Intumescent firestops are provided horizontally at each floor level, around all window & door openings and vertically at all compartment wall junctions	**Prater:** Booth Muirie BM120 rainscreen system, incorporating Alucabond Plus ACM panel, 80mm Kingspan K15, aluminium helping hand system & intumescent fire stopping.**Others:** Y-Wall board, insulated SFS system. **Structal**: Alucobond PE rainscreen panel, Rockwool duoslab insulation	ACM Rainscreen System **Structal:** SUK-RS	Alucabond Plus: Low RiskKingspan K15: Low Risk	Structal confirm the installation is compliant at the time of construction and in accordance with the relevant Building Regulations at Financial Close.

Appendix B Fire Modelling

1 Scenarios

1.1 Queen Elizabeth University Hospital Room Fire

In order for a fire in a hospital room to ignite the external cladding such a fire would need to be sufficiently large to cause flames to extend beyond the room of fire origin (i.e. out the window). This would require the fire to become ventilation controlled, following flashover and ignition of all combustibles in the room. In order for the fire to become this large, there are several assumptions that must be made:

- The sprinkler system fails operate
- The furnishings in the room are not fire retardant
- No first aid firefighting or fire brigade intervention occurs

It should be noted that due to the presence of an automatic detection and alarm system, it is expected that both firefighting intervention and evacuation would begin early in the scenario, however this has not been included in the scenario QEUH Room Fire

1.2 Model Input Data

In this scenario, a fire is considered that ignites in a single bed room. A medium growth fire has been used, based on Table 3 of PD 7974-1 (BSI, 2003, p. 26) and the similarity in the fuel load to the furniture found in a hotel room. The fire would continue to grow until it reaches a sufficient size to cause flashover (a sudden transition from a localised fire to the ignition of all exposed flammable surfaces within an enclosure (BSI, 2003, p. 5)) in the room. The size of fire required to cause flashover varies based on both the size of the room and the size of the available ventilation. Thomas's flashover correlation (BSI, 2003, p. 29) has been used to estimate the fire size required for flashover in several rooms in Table 1 below. Then, based on a medium growth fire, the time after ignition for the room to reach flashover is determined.

Table 1 Flashover correlations and time to reach flashover

Room Length (m)	Room Width (m)	Room Height (m)	Window Width (m)	Window Height (m)	Heat Release Rate to cause Flashover (kW)	Time to Flashover (based on a medium growth t2 fire) (s)
5	5	2.7	4	1.5	3542	543
8	8	2.7	6	1.5	5769	693
10	10	2.7	7	1.5	7182	774

It is noted that as pyrolysis is not modelled by Computational Fluid Dynamics (CFD) models, including FDS, this prediction is not possible to make via computer modelling.

After flashover, the fire becomes ventilation controlled (i.e. the size of the fire is limited by the available oxygen). Equation 33 of PD 7974-1 (BSI, 2003, p. 37) Uses the calorific value of the fire load, and the mass burning rate of the fuel to estimate the Heat Release Rate (HRR) of the fire at this stage. The mass burning rate of the fuel is estimated using equation 35 of

PD7974-1 (BSI, 2003, p. 38) and the dimensions of the ventilation source. For the purposed of this scenario, it is assumed that there is full fallout of the window in the room of fire origin at the time of flashover. A calorific value of 20 MJ/kg has been assumed based on an average of the values in Table 10 of PD 7974-1 (BSI, 2003, p. 37) in producing

Table 2 below, which provides examples of the HRR of ventilation controlled fires.

Table 2 HRR of ventilation controlled fires

Window Width (m)	Window Height (m)	Heat Release Rate of Ventilation Controlled Fire (MW)
4	1.5	13.2
6	1.5	19.8
7	1.5	23.1

It is noted that as the combustion is predominately outside the room at this point in the scenario, the exact HRR is not a critical factor, so long as there is a plume outside the window to ignite the cladding. In order to minimise the computation time (in general, larger fire require longer computation time), a fire of 16MW has been chosen as this will be sufficient to create a fire plume emanating from the window.
The ignition temperature of polyisocyanurate is 445°C (Hasemi, 2016). The aluminium surface would have lost a significant proportion of its strength at this temperature as the melting point of aluminium is in the range 550-600°C and it loses roughly 50% of its strength at 200°C (O'Connor, 2016, p. 3257). It was considered conservative to allow the cladding to ignite while the aluminium would be partly intact, therefore the cladding is considered to ignite at 450°C
The panes of the double glazed window of the upper room are considered to break at 300°C. Cracking of glass is primarily due to temperature differentials across the glass (BSI, 2011, p. 118), therefore it is anticipated that the windows will break due to flame impingement from the external plume and the temperature at which the window would break is not critical to this analysis. The glass is considered to completely fall out to allow the maximum ingress of smoke and hot gases from the fire in the room below.
Conditions in the room above the fire are assessed based on smoke in the room being tolerable to staff, as patients who cannot self-evacuate are expected to be bed bound and below the head height of the staff. Based on a willingness to move through smoke, the room is considered to be untenable if the visibility is reduced below 10m (BSI, 2004, p. 15), or the temperature within the room exceeds 60°C (BSI, 2004, p. 17).
The parameters shown in

Table 3 were used in the setup of the FDS Model for the room fire

Table 3 - FDS Model Input Data

Design Fire	16MW
Fire Location	Initiated in a bed, burning predominantly occurs in the window plume
Ventilation	Window 6m x 1.5m Window considered to break at 300°C, correlating with flame impingement
Run Time	3600 s (1 hour)
Tenability	60°C, visibility 10m
Cell Size	0.25m
Key Events	• Time fire becomes ventilation controlled (taken to be time of flashover) • Time for ignition of cladding • Time for window in upper room to break • Time to untenability of upper room

A general view of the model is presented in Figure 1.

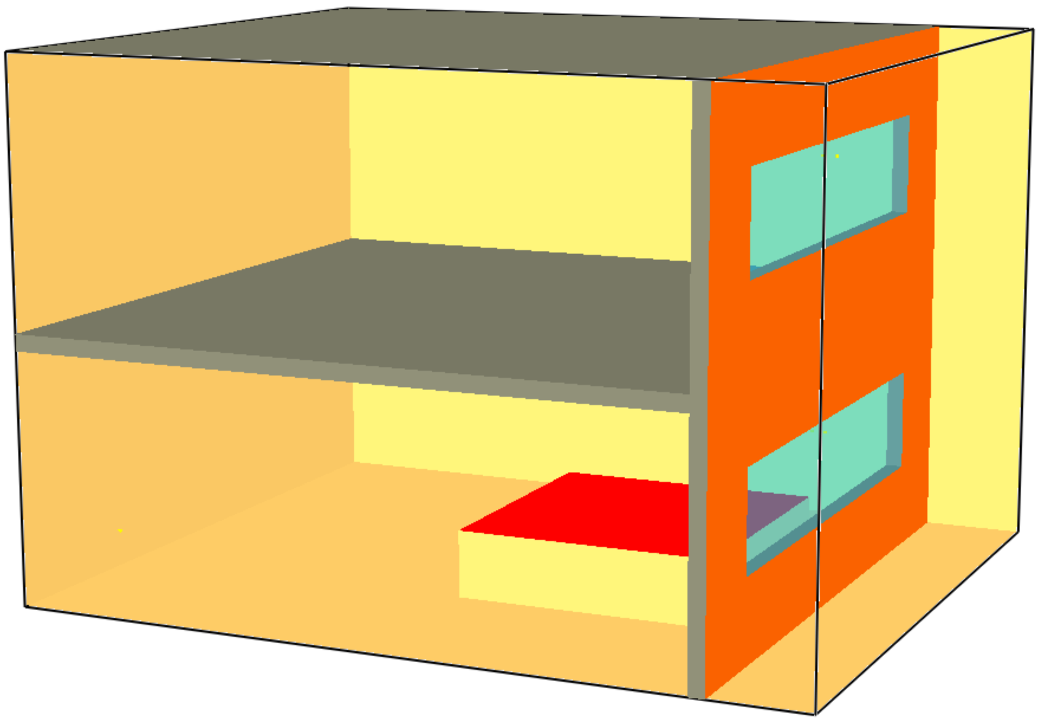

Figure 1 A general view of the model

1.3 Model results

As expected, the fire became ventilation controlled and the combustion occurred mainly near and beyond the window of the room of fire origin, as shown in Figure 2, below. The cladding ignited approximately 3 minutes after flashover, as shown in Figure 3 and Figure 4. However, by this time, conditions had already become untenable in the room above the room of fire origin.

Figure 5 shows that the window of the upper room break to due flame impingement approximately 20 seconds after the fire flashes over in the lower room. At this time a significant quantity of smoke enters the upper room through the broken window and the visibility drops below the tenability limit in approximately ten seconds (i.e. 30 seconds after flashover) as shown in Figure 6. Due to the heat of the gases entering the room, the temperature tenability criterion is reached approximately one minute after flashover (see Figure 7 and Figure 8).

At the end of the simulation time (one hour after ignition), the temperature in the upper room is approximately 400°C, as shown in Figure 9

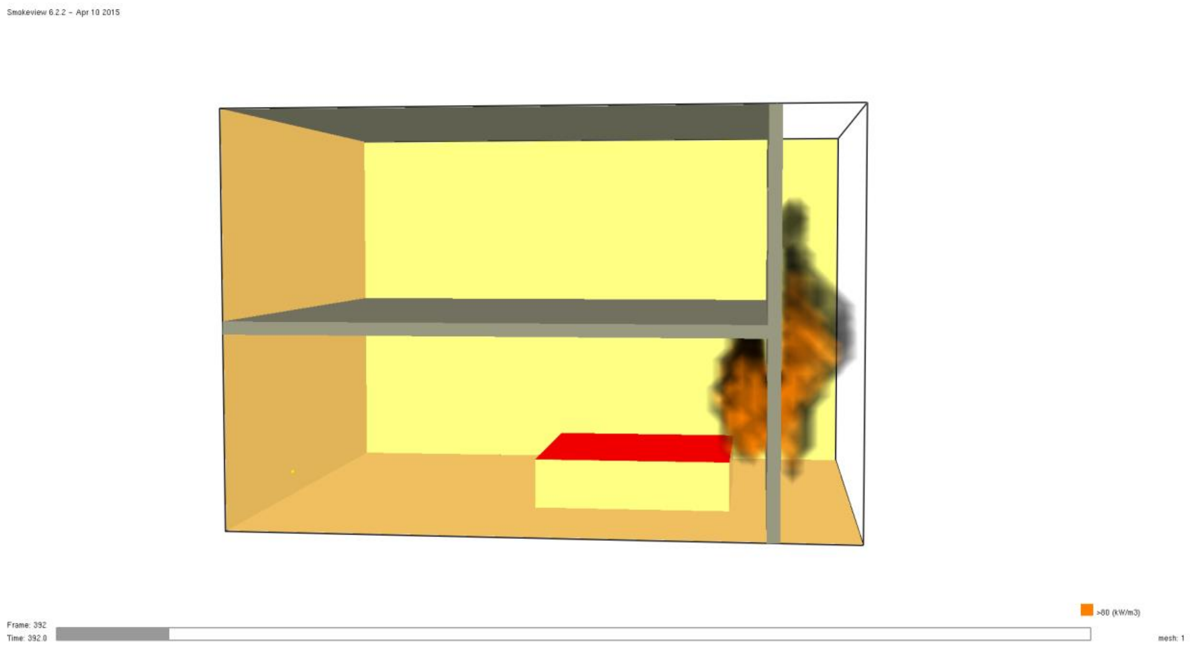

Figure 2 Location of Combustion after the fire becomes ventilation controlled at approximately 5 minutes of simulation

(NB that due to the lack of ability to model flashover, this does not indicate that actual time to flashover expected and as detailed in Section 1.2)

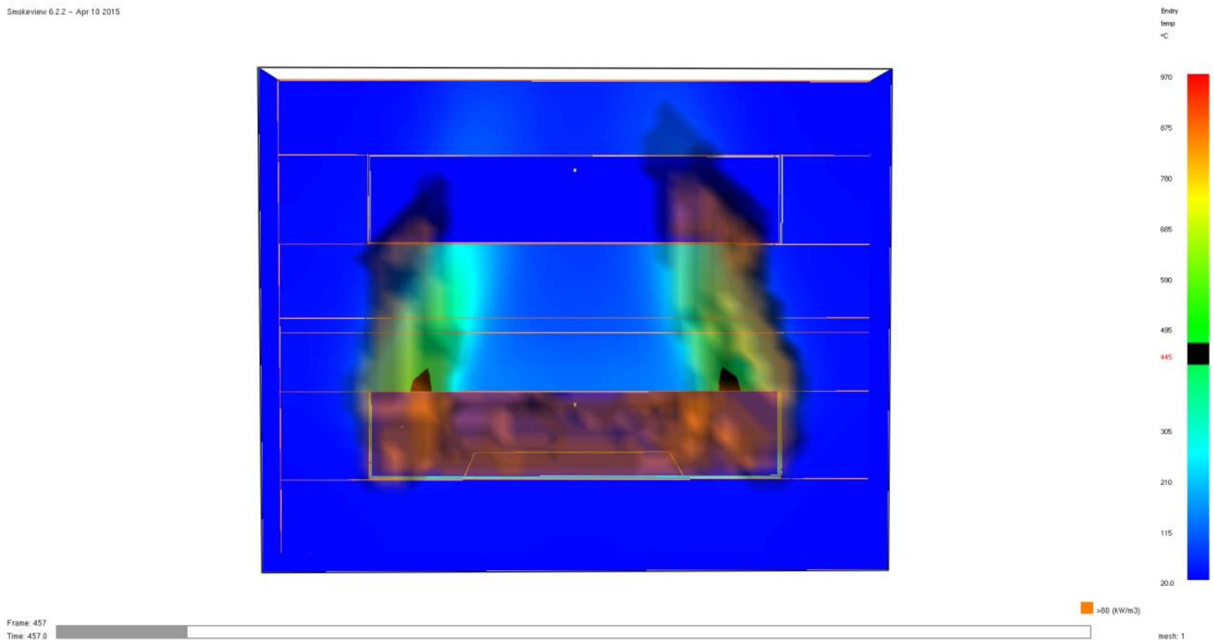

Figure 3 Ignition of the cladding approximately 3 minutes after flashover

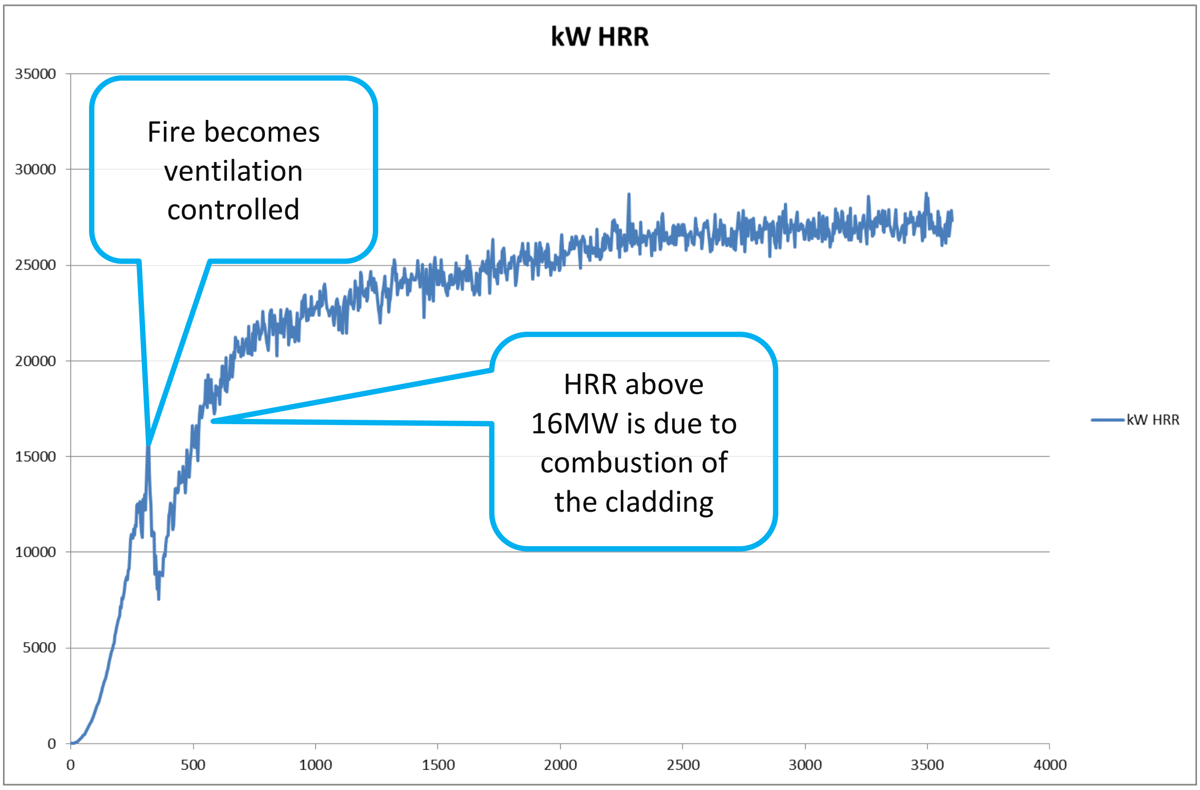

Figure 4 HRR during the simulation

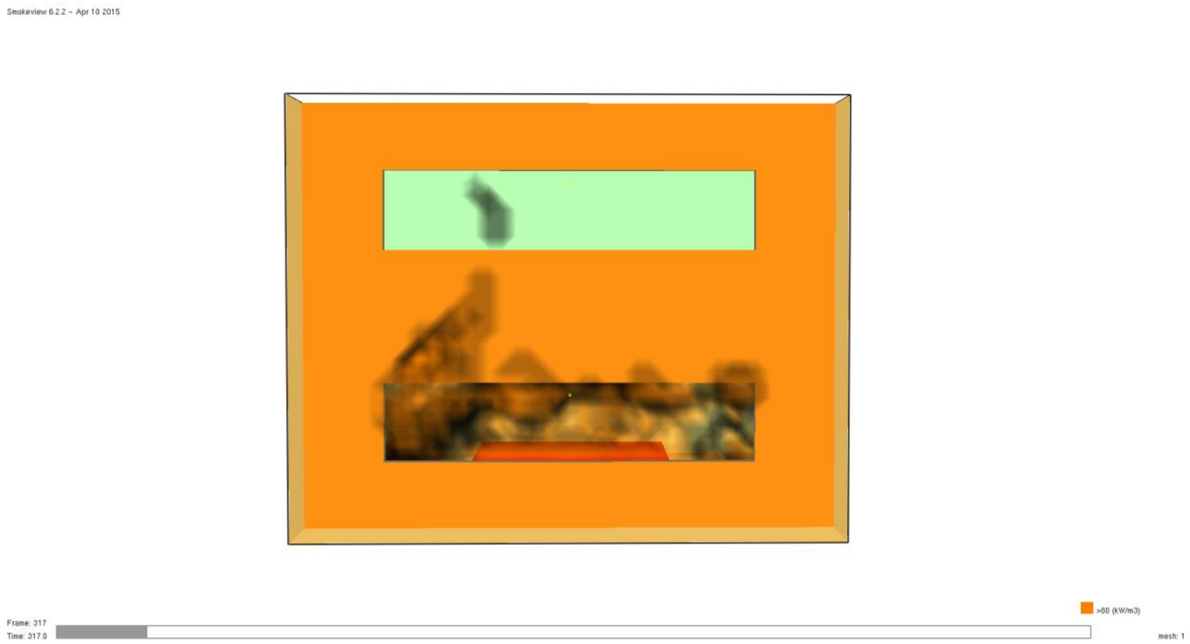

Figure 5 Breakage of the upper room window occurred due to flame impingement approximately 20 seconds after flashover

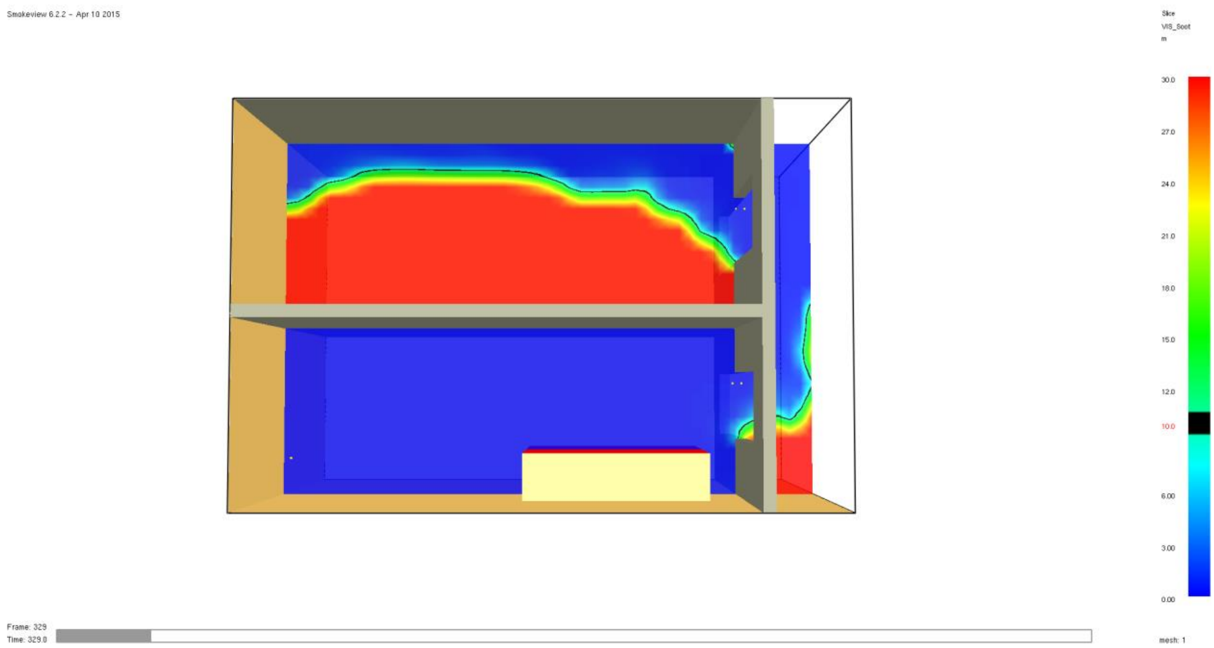

Figure 6 The visibility in the upper room becomes untenable approximately 30 seconds after flashover

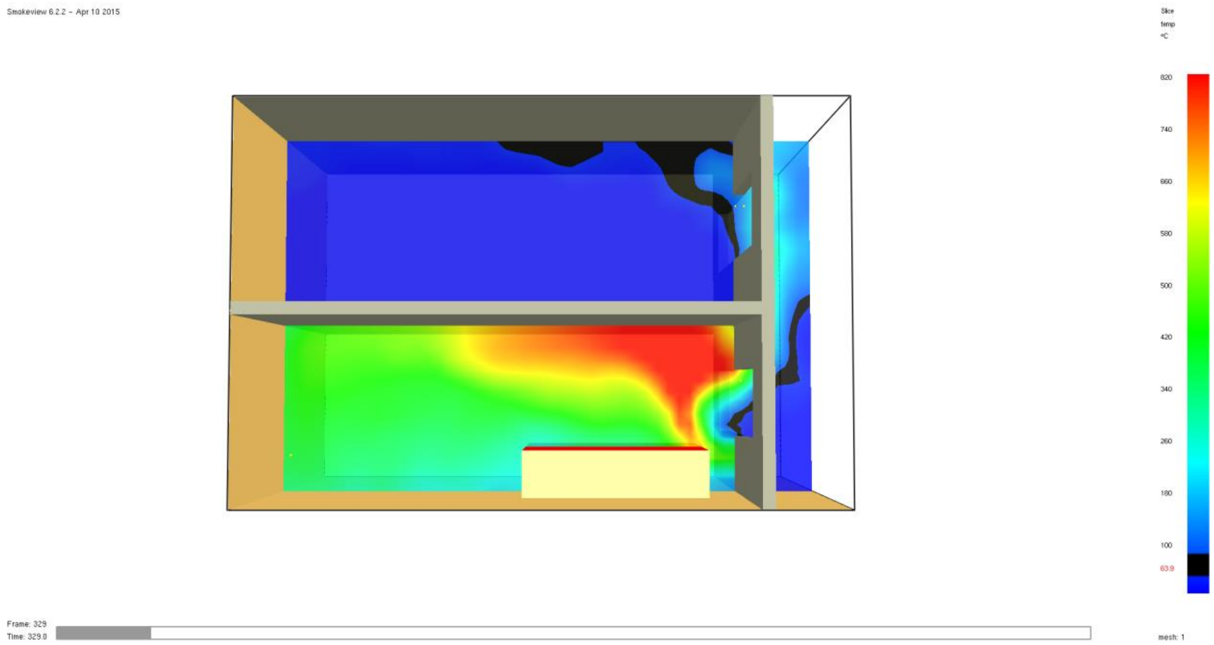

Figure 7 Temperatures within the upper room are still tenable when the visibility becomes untenable

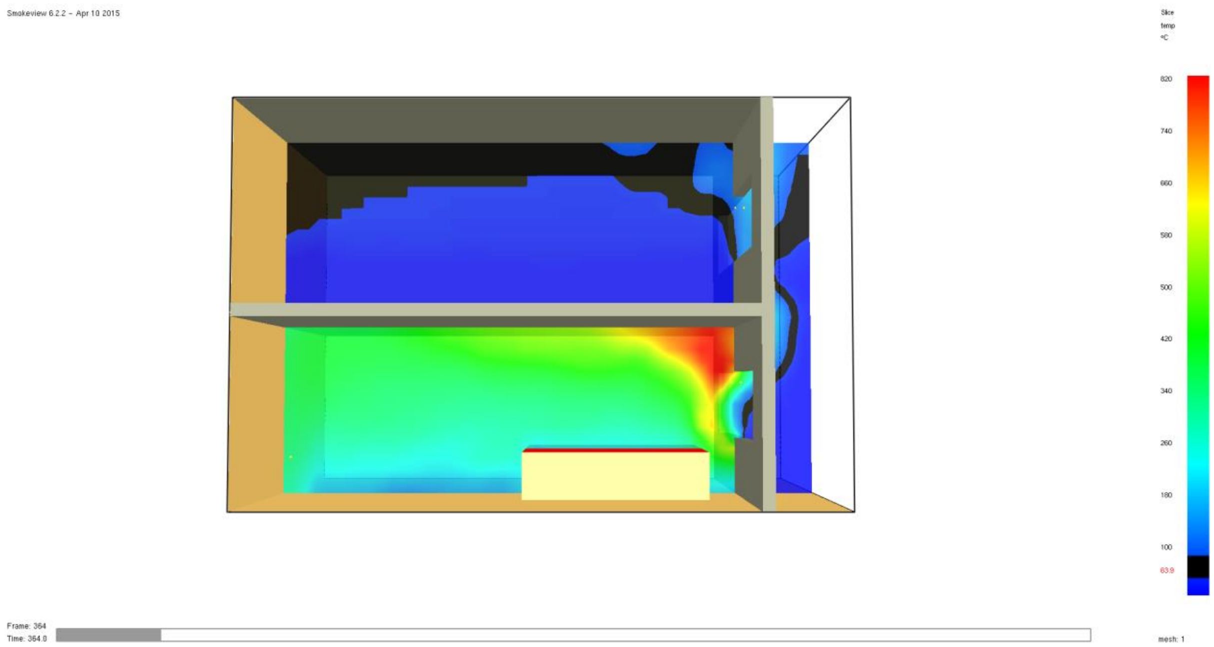

Figure 8 Temperatures within the upper room reach the tenability criterion approximately one minute after flashover

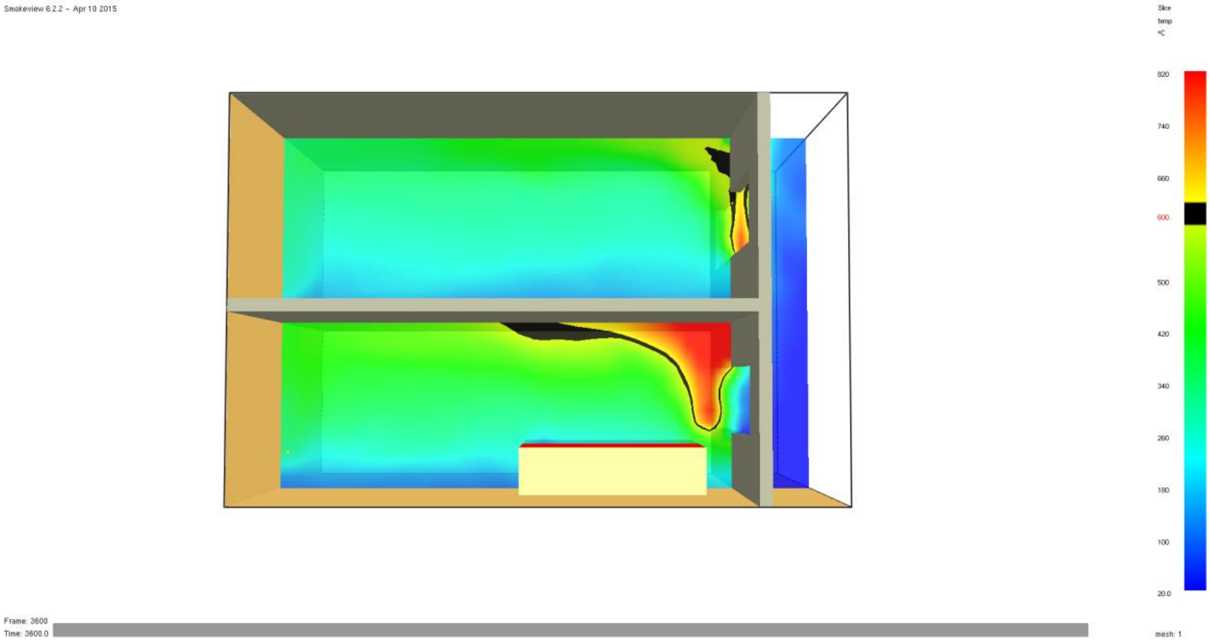

Figure 9 Temperature in the upper room at the end of the simulation period (note that the temperature in the lower room is underestimated due to the focus of the modelling on the external plume)

1.4 Discussion

In the scenario modelled, the cladding was ignited by a fire plume that was external to the building. The cladding ignited approximately 3 minutes after flashover in the room of fire origin, which resulted in a fire plume being attached to the external wall.

In order for a fire to reach flashover (and produce an external fire plume), it is noted that there would need to be sufficient combustible material in the rooms (i.e. the furnishings in the room are not fire retardant) and no first aid firefighting or fire brigade intervention occurs. Additionally the sprinklers would have to have failed to control the fire.

In all cases, conditions in the rooms adjacent to the fire plume had become untenable prior to ignition of the cladding. There was no significant lateral spread of fire along the façade, therefore other rooms are unlikely to be affected by the scenarios that have been considered.

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